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By Karl Z. Morgan

Health Physics is a new name applied to a newly developed and specialized branch of Radiology. The name, Health Physics, has been used on the Manhattan Projects during the war to refer to a science which has been developed and devoted to the study of penetrating radiations and the prevention of radiation exposure of personnel. Thousands of persons have been employed on the atomic energy projects at the University of Chicago, Clinton Laboratories, Hanford Engineer Works,and elsewhere, who have worked with radioactive materials equivalent to millions of times the total amount of curies of radium in all the hospitals and laboratories of the world. In spite of all this hazardous radiation, no one associated with any of these three projects has been injured by radiation in so far as can be determined by the Health Physicists, millions of instrument measurements, and by the Medical Departments from very thorough and frequent medical examinations. This record is rather remarkable when one recalls that hundreds of people have been killed and many injured in the past from improper handling of radium and X-ray equipment.

The Health Physics Divisions at these locations have put forth an enormous effort to prevent radiation damage. It is only by their untiring efforts and with the full cooperation of all concerned that such a record may be maintained.

At Clinton Laboratories there is a Health Physics Department[1] consisting of seventy physicists, chemists, engineers, and laboratorians. The purpose of this article is to describe some of their activities with the view that similar efforts may be encouraged elsewhere in preventing radiation damage.

The principal function of the service section of the Health Physics Department has been to prevent persons from exceeding certain tolerance levels of radiation. When the atomic energy projects began there was some doubt as to what constituted safe tolerance levels for the various types of radiations. The International Congress of Radiobiology in 1934 had already set the tolerance for X and gamma radiation at 200 mr/day (milliroentgens per day). The American Advisory Committee on X-ray and Radium Protection set the tolerance for X and gamma radiation at 100 mr/day. After a careful examination of the radiation records, it was decided to set 100 mr/day as the tolerance level for X and gamma radiation on the atomic energy projects.

The choice of suitable tolerance levels for neutrons was more difficult. Experiments[2,3] had indicated that fast neutrons are probably about five times as damaging to tissue as X or gamma rays. Therefore, the tolerance level for fast neutrons was set at 20 mreps/day (milliroentgens equivalent physical per day).*

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* Since the "roentgen" is defined only in terms of the absorption of the secondary electron energy produced in air by X and gamma radiation, a new, equivalent physical unit was needed. This new unit was called the rep (roentgen equivalent physical) which is the intensity of radiation such that it may be absorbed at the rate of 83 ergs per gram of tissue. A rep becomes a roentgen if the radiation is X or gamma and the absorption takes place in air. The rep is sometimes defined as the dose of radiation corresponding to the production of ion pairs at the rate of 1.615×10^{12} per gram of air in a microscopically small cavity in the medium at the point concerned. The need for some such unit is apparent but its exact definition should be agreed upon by an international organization.

It should be emphasized here that tolerance radiation is not what one attempts to receive each day but it is rather the "maximum permissible dose" per day. There is considerable evidence that 100 mr/day, received each day for a few years, will not produce any damage to man. However, the hereditary effects of radiation are additive, and with the present existing limited data one can not state with certainty that it is safe to receive this rate of exposure regularly over a period of thirty or forty years. At Clinton Laboratories an attempt is made not to receive any radiation (other than natural background radiation). As a consequence, and in so far as the accuracy of our measurements is concerned, no one has averaged over 10 mr/day while employed at Clinton Laboratories. This is probably fortunate because there is some reason to suspect that man should not receive during his lifetime an accumulated total-body dose in excess of 1000 roentgens to the male and 100 roentgens to the female. Animal experiments* indicate that the ovary is one of the most sensitive body organs to radiation and that there may be an increased incidence of ovarian tumors beginning with an accumulated dose of 100 roentgens of total-body radiation. The limiting value for a male should probably be set at 1000 roentgens of total-body radiation because there is a possible shortening of his life span and other undesirable results may accrue for accumulated doses in excess of this amount. Table 1 gives the tolerance levels set at Clinton Laboratories for the principal radiations encountered.

Table 1. Tolerance or maximum permissible exposure to radiation adopted at Clinton Laboratories.

Type of radiation	mr/day	mrep/day	mrem/day †
X ray	100	100	100
Gamma	100	100	100
Beta	---	100	100
Fast neutron	---	20	100
Thermal neutron	---	~ 50	100
Alpha*	---	10	100

* This alpha tolerance level is considered only from the standpoint of internal irradiation effects.

† As indicated by this table, the rem (roentgen equivalent man) is the amount of radiation that will produce the same damage to man as the roentgen. The rep and rem units were introduced into the project literature by H. M. Parker.

The values in Table 1 are in general for total-body irradiation. However, at Clinton Laboratories these tolerance levels are applied also to local exposure from very narrow beams of radiation and to external and internal exposure from contaminating radioactive isotopes. In the case of beta irradiation to the hands, it is sometimes permitted that one receive 200 mrep/day but, in general, this level is maintained at 100 mrep/day.

The principal hazard from alpha and beta radiating isotopes on the hands and clothing is from the inhalation and ingestion of these products and their ultimate fixation in the human system. A four-fold hand counter is used to check the beta and gamma activity of the hands. This instrument counts both sides of each hand and the shoes of a person in 24 seconds. It uses Geiger-Mueller (GM) counters and starts automatically when one steps on the platform and places his hands in the counting

* Some of the animal experiments lending support to this view have been carried on by E. Lorenz et al of the National Cancer Institute and L. O. Jacobson et al of the Metallurgical Laboratory in Chicago, Illinois.

pockets. Five recorders, operating from scaling circuits, indicate the hand and shoe contamination, and the unit terminates the count automatically after 24 seconds. The other parts of a person's body and clothing should be checked for beta and gamma contamination with Geiger-Mueller probes. The alpha contamination is checked with a proportional counter unit which is called "poppy."*

There is a special decontamination laundry operated at Clinton Laboratories. Regular washing procedures with the use of detergents remove the dirt from the garments and a citric acid solution is used to remove the fission products and plutonium contamination. All individual garments are checked for alpha, beta, and gamma contamination after they are washed.

Another problem is to check desk tops, stools, hoods, apparatus, etc. for contamination. These surveys are made with electroscopes such as the Lauritsen or L and W, electronic meters such as the C. P. meter and the Zeus,* and various types of probe meters such as poppy and walkie-talkie GM units. Some of the tolerance levels as used at Clinton Laboratories are indicated in Table 2.

Table 2. Tolerance levels of radioactive contamination at Clinton Laboratories.

Measurement	Instrument used	Tolerance levels
Hand	Four fold hand counter	100 scaler units = 700 counts/min $\sim$ 1 mr/hr of β and γ.
	Poppy	0 disintegrations/min of α from area of 150 cm^2.
Shoe (outside)	Foot counter	30 scaler units = 10,000 counts/min $\sim$ 14 mr/hr of β and γ.
Shoe (inside)	Shoe probe	1,000 counts/min $\sim$ 1/3 mr/hr of β and γ.
Clothing	Laundry counter	500 counts/min $\sim$ 1/3 mr/hr of β and γ.
Clothing, shoes, etc.	Poppy	1,500 disintegrations/min of α from area of 150 cm^2.
Body	Poppy	500 disintegrations/min of α from area of 150 cm^2.
Thyroid	GM probe counter	800 counts/min with counter against throat ($\sim$ 1,000 mr/24 hr in thyroid).
Table tops, floors, etc.	Poppy	2,000 disintegrations/min of α from area of 150 cm^2.
	GM probe counter	300 counts/min with counter in contact ($\sim$ 0.1 mr/hr at counter).
Table tops, floors, etc. but protected from handling	Poppy	10,000 disintegrations/min of α from area of 150 cm^2.

*The four-fold hand counter was developed by H. M. Parker, the poppy by C. J. Borkowski, the L and W by O. G. Landsverk and E. O. Wollan, the C. P. meter by C. O. Ballou, and the Zeus by F. R. Shonka.

Table 2. Tolerance levels of radioactive contamination at Clinton Laboratories. (Continued)

Measurement	Instrument used	Tolerance levels
Inside intermittently used hood	Poppy	30,000 disintegrations/min of α from area of 150 cm^2. (A hood containing >1 μg of plutonium or isotopes of a similar hazard shall be marked "High Level Hood.")
Smear tests on table tops, floors, apparatus, etc.	2 sq. in. filter paper smeared over ~ 12 sq. in. and counted with β and γ and α counters.	0 disintegrations/min of α. 200 counts/min of β and γ.
Boxes for shipment by air or rail	Smear tests Electroscope	0 disintegrations/min of α, β, and γ. $<$ 50 mr/hr at the surface of package.
Truck shipments	Electroscope	50 mr/hr at rear wheels of truck and less than 100 mr/day in cab for trip.
All laboratory and operating areas	Electroscope, C.P. meters, etc.	All areas with radiation >12.5 mr/hr shall be roped off and have signs posted.

All the GM counters used above, with the exception of the thyroid counter, are standard Eck and Krebs thin-walled glass counters with an effective flat plate area of $\sim$ 5.4 cm^2. They are filled with neon-ethel ether gas and have a low thermal and photo sensitivity. The thyroid counter is a gamma sensitive brass wall counter.

Another problem of considerable concern to the Health Physicist is the concentration of radioactive isotopes in the air and water in the vicinity of the plant site. The gamma activity of the waste water from the plant is measured several times daily by means of GM counters and ionization chambers submerged in the water or suspended above the water surface, while the beta activity is measured from evaporated water samples by means of thin-walled beta GM counters. The air radioactivity in the neighborhood of the plant is measured with continuously recording GM counters and ion chambers. The level of radioactive gases, such as argon and xenon inside the laboratories, is measured by collecting air samples in vacuum tanks and counting the gas radioactivity later with a GM counter. The activity of suspended radioisotopes in the air is determined by collecting dust samples with a precipitator or by means of a filter paper apparatus. These samples are counted for α, β, and γ radioactivity. The radioactive elements that are collected from the air are identified by means of decay curves and by energy measurements with the aid of a pulse analyzer. Table 3 indicates the general tolerance levels[4] that are used until the contaminating isotope is identified.

The Health Physics Department at Clinton Laboratories employs about twenty men in the Research and Development section. This section is responsible for the solution of many theoretical and experimental problems relating to the control of radiation. The Survey and Monitoring section employs about fifty men. It is this survey section that goes into the laboratories and production areas and makes a continuous search for radiation hazards. There are thirty different kinds of instruments in everyday use by these surveyors, and these surveyors must know what instrument to use, when to use it, and how to interpret the results. Most of these instruments were developed at the University of Chicago and Clinton Laboratories. Unfortunately, at present very few of these instruments have been declassified and made available to institutions outside the Manhattan Projects. It is hoped that

Table 3. Tolerance concentration of radioactive substances in the air and water at Clinton Laboratories.

Element	Tolerance concentration in air (μ c/cc)	Tolerance concentration in water (μ c/cc)
General β or γ emitters	10^{-7}	5×10^{-4}
General α emitters	3×10^{-11}	10^{-5}
General equations for β or γ submersion tolerance	$\frac{2.1}{E} \times 10^{-6}$*	$\frac{1.6}{E} \times 10^{-3}$*

* These two equations apply to most of the radioisotopes and can be used in determining tolerance concentrations in cases in which the external exposure is greater than the internal exposure. These equations should not be used in determining the tolerance values of radioisotopes like Sr^{90}, Sr^{89}, Ba^{140}, or I^{131} which have a large retention factor in the human body. The term E in these equations is the average energy in Mev.

this condition will be remedied in the near future. Perhaps most of the institutions working in the atomic energy field will not need as many Health Physicists and instruments as are employed at Clinton Laboratories, but it is considered very desirable that they begin with a few dependable instruments and a nucleus of men trained in this field who are charged specifically with Health Physics problems. Through experience at Clinton Laboratories it has been observed that scientists and production men alike become so absorbed in their own problems that it is difficult for them to be forever vigilant and constantly concerned with the insidious hazards of radiation. It is too easy for them to overlook a defective shield and that invisible beam which passes through the wall so that the person in the adjacent laboratory receives a serious exposure; or it would not take long for a careless person to fixate one ten millionth of a curie of a long-lived alpha emitter in his body and that is possibly a fatal amount of some of the isotopes. Preliminary plans are being made for a Health Physics training program at Clinton Laboratories and those who are interested should contact this department.

When a person enters the restricted area of Clinton Laboratories he must wear personnel monitoring instruments. The film meter is the most important of these. It contains a dental-size film packet holding two gamma-sensitive films. One has a range from about 20 mr to 3,000 mr and the other from 500 mr to 20,000 mr. The film meter has a cadmium shield one millimeter thick and an open window. After the film is worn for a specified time, it is developed and the darkening is read with a photometer. The opaqueness of the film that was behind the cadmium is proportional to the roentgens of X and gamma-ray exposure and is relatively independent of the energy of the radiation. The darkness of the film that was behind the open window gives an indication of the very soft X-ray and the beta exposure. Occasionally the film that was behind the cadmium is darker than that which was behind the open window. In all such cases it has been established that the wearer of the film was working where he was exposed to thermal neutrons. This $Cd^N(n, \gamma)Cd^{N+1}$ reaction gives a qualitative indication of thermal neutron exposure. Persons who are to work in the pile building or work with any kind of neutron sources wear a special neutron film in their badge in addition to the gamma film. This film has a 30 micron emulsion and is sensitive to protons. The portion of the film behind the cadmium shield receives proton tracks due to the fast neutron recoils, H(n,p), and the film behind the open window receives tracks due to the above reaction plus the reaction $N^{14}(n,p)C^{14}$. The films are developed after exposure and the proton tracks are counted with the aid of a dark field microscope. Tolerance for two weeks' exposure to either the fast or thermal neutrons is about 3/5 tracks per field of vision when the field of vision is 1.77 by 10^{-4} cm^2. This is assuming eight hour tolerances of 4,000 thermal neutrons per cm^2 per second and 200 fast neutrons per cm^2 per second. It is rather fortunate that the composition of the film and the cross sections for the above reactions are such as to give about the same number of proton tracks for the fast and for the thermal neutron tolerance.

In addition to the film meter, each person who enters the restricted area regularly is assigned two pocket meters. Two are worn instead of one because the meters, which are small pen-shaped air condensers, frequently discharge due to insulator leakage and rough handling. These meters are charged to 140 volts and read by the personnel monitoring girls at the end of each shift by means of a minometer. The electrical discharge is proportional to the radiation exposure and the meters have a useful range from about 10 mr to 200 mr.

Several other types of personnel radiation monitoring instruments are available to persons wishing to use them. For example, small aluminum rings containing films are frequently worn by persons working with beta-emitting isotopes or when they may find it necessary to place their hands behind the protective radiation shielding. Pocket dose meters, which are pen-shaped single fiber electrometers, can be read directly by holding them up to the light. They are recommended for operations in the neighborhood of extremely intense radiation fields where one's working time to receive the daily tolerance dose is only a few minutes.

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